

## Chapter 4

### Ice Jam Mitigation Techniques

#### 4-1. Ice Jam Flood Control

a. Until the 1970s, flood control concentrated largely on open water flood events and was considered primarily a Federal responsibility. Large structural solutions such as levees or flood control dams were built. Now the Federal government requires local and state governments to share the costs, and government policies favor small-scale, locally funded projects. In light of significantly reduced budgets, innovative ice jam mitigation techniques that require low maintenance and low up-front costs, have low environmental impacts, and yield excellent results in terms of reduced flooding damages are being developed. Many of these are appropriate for design and implementation in smaller cities and towns.

b. In 1990 FEMA initiated the Community Rating System to reward local hazard mitigation efforts by reducing flood insurance premiums in communities that adopt relocation, hazard area acquisition, and other mitigation policies. "Clearly, Federal flood hazard policy is demonstrating an increasing emphasis on mitigation... Mitigation works to change the nature of the threat, decreases vulnerability to damage and reduces exposure to the hazard" (Drabek and Hoetmer 1991).

c. A number of ice jam flood mitigation measures are possible (USACE 1982). These measures can be of a structural or nonstructural nature, appropriate to control breakup jams or freezeup jams. Some are permanent, some are deployed in advance of an anticipated flood threat, while others are deployed under emergency conditions when a jam has formed and flooding has occurred.

d. *Structural measures* for ice jam control may incorporate features that can be used to alleviate open water flooding as well as those designed specifically for ice jam flood events. The cost of such measures includes construction, operation, and land acquisition as well as costs associated with recreation and environmental mitigation. Unfortunately, while they are often very successful, structural solutions tend to be expensive. Structural solutions remain appropriate on rivers where chronic or serious threats persist and where the extent of potential damages justifies the cost. Although the majority of the structural mitigation techniques are, by their very nature, permanent, some are designed to be removable. These removable structures are usually installed at the beginning of winter and removed after spring breakup when the threat of ice jam flooding no longer exists. A few removable structures are designed to be deployed after an ice jam threat has been identified and, in this respect, can be considered advance mitigation measures.

e. *Nonstructural measures* are designed to modify vulnerability to the flood threat or to reduce the severity of the ice jam and of the resulting flood. They are generally less expensive than structural solutions. The majority of the nonstructural techniques are used for advance and emergency measures when serious ice jam flooding is imminent or under way. For example, if sufficient warning is provided, ice weakening (ice cutting or dusting) may be implemented before an ice jam occurs. Blasting and mechanical removal are often employed only as emergency mitigation measures once ice jams have occurred. The creation of ice storage zones upstream from a known jam site to minimize the amount of ice reaching the jam site is a permanent measure since these areas, once established and properly maintained, can be used year after year.

f. *Freezeup ice jam* control usually targets the production and transport of the frazil ice that causes jams. This may be accomplished by encouraging the growth of an ice cover that insulates the water beneath, decreasing the production of frazil ice. The ice cover collects and incorporates frazil ice that is transported from upstream. This reduces the amount of ice moving downstream.

g. *Breakup ice jam* control focuses on affecting the timing of the ice cover breakup, thereby reducing the severity of the resulting jam to the point where little or no flooding occurs, or on controlling the location of the ice jam by forcing the jam to occur in an area where flooding damages will be inconsequential.

h. Table 4-1 summarizes the currently available jam mitigation techniques and indicates whether they are applicable to freezeup or breakup jams and whether they are appropriate for permanent, advance, or emergency measures. In the

**Table 4-1**  
**Ice Jam Mitigation Methods**

Technique	Jam Type	Type of Mitigation
<b>Structural</b>		
Dikes, levees, floodwalls	F, B	P
Dams and weirs	F, B	P
Ice booms	F, B	P, A
Retention structures	B	P
Channel modifications	F, B	P
Ice storage zones	B	P, A
<b>Nonstructural</b>		
Forecasting	F, B	A, P
Monitoring and detection	F, B	E, A, P
Thermal control	F, B	E, A, P
Land management	F, B	P
Ice cutting	B	A
Operational procedures	F, B	A, P
Dusting	F, B	E, A
Ice breaking	F, B	E, A
Mechanical removal	F, B	E, A
Blasting	F, B	E, A
<b>Traditional Techniques</b>		
Floodproofing	F, B	P
Sandbagging	F, B	A, E
Evacuation	F, B	A, E
Levee closing	F, B	A, E
Key: B = Breakup jam, F = Freezeup jam, P = Permanent measure, A = Advance measure, E = Emergency measure		

following sections, the ice jam mitigation methods are described in detail: first, those that are primarily permanent measures; second, those appropriate for advance measures; and third, those applicable to emergency situations. Traditional flood fighting methods, namely floodproofing, sandbagging, levee closing, or evacuation, are obviously applicable to ice jam floods. They are only briefly summarized under the pertinent sections.

*i.* The best mitigation strategy often combines structural and nonstructural measures, such as an ice boom associated with temporary modifications in the operation of an upstream water control dam, as well as permanent, advance, or emergency measures. Table 3 lists common ice jam mitigation strategies and corresponding techniques.

*j.* When an ice jam control program is developed following an ice jam flood event to prevent similar events from recurring, it is necessary to determine the type of jam, source of ice, local and remote causes of the jam, and meteorological and hydrological conditions that led to the jam formation. An ice jam data collection program, as described by White and Zufelt (1994) or Elhadi and Lockhart (1989), should be an integral part of an ice jam mitigation effort to address all of these points.

*k.* Data collection should not be limited to the immediate vicinity of the jam location. It is important to study upstream and downstream areas since the source of ice and the actual causes of ice jamming at a particular site may be far removed from the actual jam location. This data gathering phase of the program is critical to select the jam mitigation strategy and corresponding mitigation techniques best appropriate to the site under study.

*l.* Successful ice jam mitigation often requires multijurisdictional cooperation and interagency coordination. For example, a catastrophic breakup ice jam on the Delaware River in February 1981 affected three states and caused

**Table 4-2**  
**Ice Jam Mitigation Strategies and Applicable Techniques**

Protect surrounding areas from flood damages

- Dikes, levees, and floodwalls
- Floodproofing
- Floodplain land use management
- Sandbagging
- Levee closing
- Evacuation

Reduce ice supply

- Thermal control
- Revised operational procedures
- Ice booms
- Dams and weirs
- Ice storage zones
- Dusting
- Ice retention

Increase river ice and water conveyance

- Channel modifications
- Revised operational procedures

Control ice breakup sequence

- Detection and prediction
- Ice booms
- Ice retention
- Ice cutting
- Ice breaking
- Revised operational procedures

Displace ice jam initiation location

- Dams and weirs
- Ice piers, boulders, and cribs
- Ice booms
- Ice breaking
- Channel modifications

Remove ice

- Thermal control
- Ice breaking
- Mechanical removal
- Blasting

\$14.5 million in damages. After extensive collaboration between Federal and state agencies in New Jersey, Pennsylvania, and New York, a diversion channel was proposed to be built physically in New Jersey that also provided major flood loss reduction benefits to New York and Pennsylvania.

#### **4-2. Permanent Measures**

*a. Dikes, levees, and floodwalls.* Dikes, levees, and floodwalls physically separate the river from property to be protected. These measures protect against open water floods as well as ice jam floods. However, designs adequate for open water protection may not be adequate to handle ice jam stages that cause physical damage.

*b. Dams and weirs.*

(1) Dams are used to affect the thermal and flow regimes of a river. As breakup jam control structures, dams are designed to suppress or change the duration or timing of ice jam formation downstream by intercepting the solid ice



**Figure 4-1. Lancaster, NH, structure**

able and can be seasonably deployed. However, they often require local bed and bank protection against scour for stability and effectiveness. Provisions to allow part of the flow to divert around the structures to limit the upstream flow depth may be required.

*c. Ice booms.*

(1) Ice booms are the most widely used type of ice control structure (Figure 4-4). They are a series of timbers or pontoons tethered together and strung across a river to control the movement of ice. Booms are flexible and can be designed to release ice gradually and partially when overloaded. Ice booms are relatively inexpensive and can be placed seasonally to reduce negative environmental impacts.

(2) Booms commonly stabilize or retain an ice cover in areas where surface flow velocities are 0.76 m/s (2.5 ft/s) or less and relatively steady. In some cases, a weir or small structure can improve hydraulic conditions at the ice boom location, especially on small, steep streams. Some booms are located at the outlets of lakes or reservoirs to keep ice from entering downstream ice-jam-prone reaches.

(3) Conventional ice booms may be used in breakup situations to hold back the ice for a brief time, allowing the initiation of emergency response measures such as evacuation or sandbagging. Booms can be placed to direct the movement of ice pieces away from an intake or navigation channel. Ice control booms are also used to promote ice cover formation during freezeup as part of freezeup ice jam mitigation efforts.

*d. Ice retention.*

(1) Ice retention structures control breakup jams by promoting the initiation of an ice jam at a suitable location where flooding will create little or no damage. Fragmented ice is captured and retained upstream from the retention structure to create the ice jam. Ice retention structures can range from suspended structures such as a submarine net or vertically oriented ice booms, to streambed structures such as concrete piers (Figure 4-5), large boulders, or rock-filled cribs placed at regular intervals across the width of the stream. Provision for a floodplain or diversion channel may also be required

pieces incoming from upstream. For freezeup jam control, a dam promotes the formation of an upstream stable sheet ice cover in order to minimize the generation of frazil ice and the consequent formation of a freezeup jam.

(2) For example, gates may be designed to allow run-of-river flow during most of the year, but in the winter are closed at freezeup so rapids are inundated (Figure 4-1). This eliminates local frazil ice production, reduces the supply of frazil moving downstream, and slows the freezeup jam progression.

(3) A dam designed to reduce ice jam flooding can be part of a multiobjective community project where benefits for open water flood control, navigation, recreation, water supply, irrigation, or hydropower justify much of the construction costs.

(4) For smaller rivers, when financial or environmental constraints eliminate consideration of major structural works, relatively low-cost alternatives can still provide significant ice jam control. For freezeup control, a still-experimental fabric tension weir (Figure 4-2) supported by cables anchored at the banks may be an economically feasible alternative. For breakup control, a permeable, cable-supported wire mesh (similar to submarine net (Figure 4-3)) may be strung across the stream to temporarily hold ice from upstream while the downstream reaches of the stream are cleared of ice. These two types of structures are remov-



Figure 4-2. Tension weir

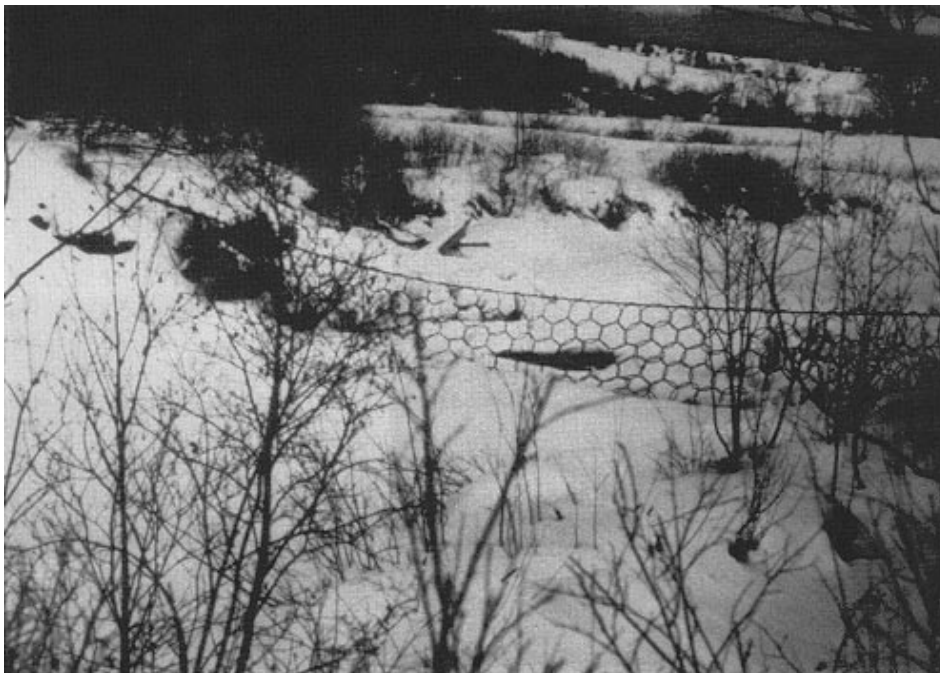
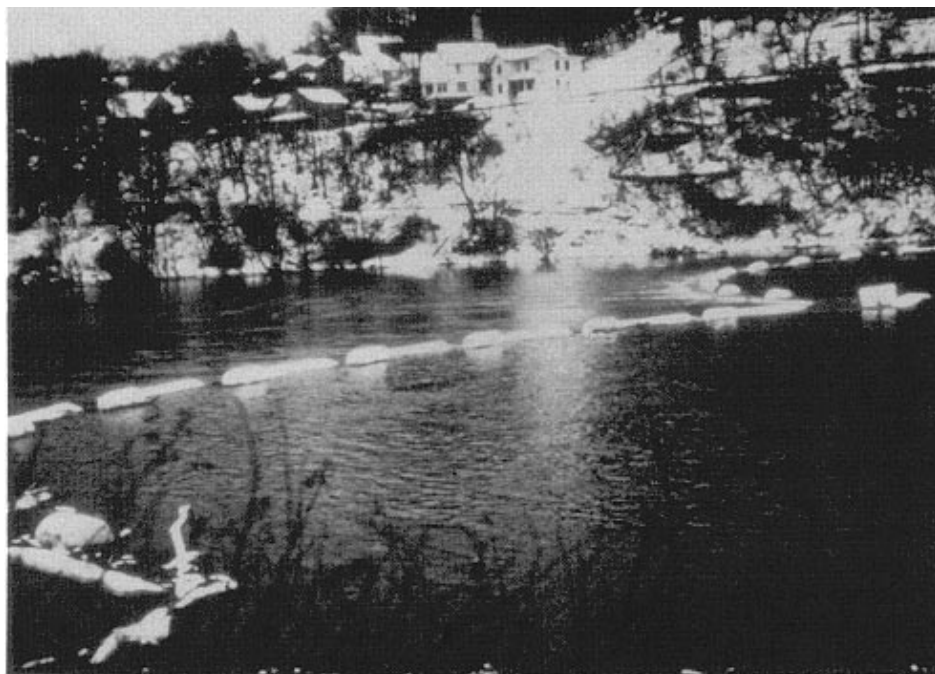
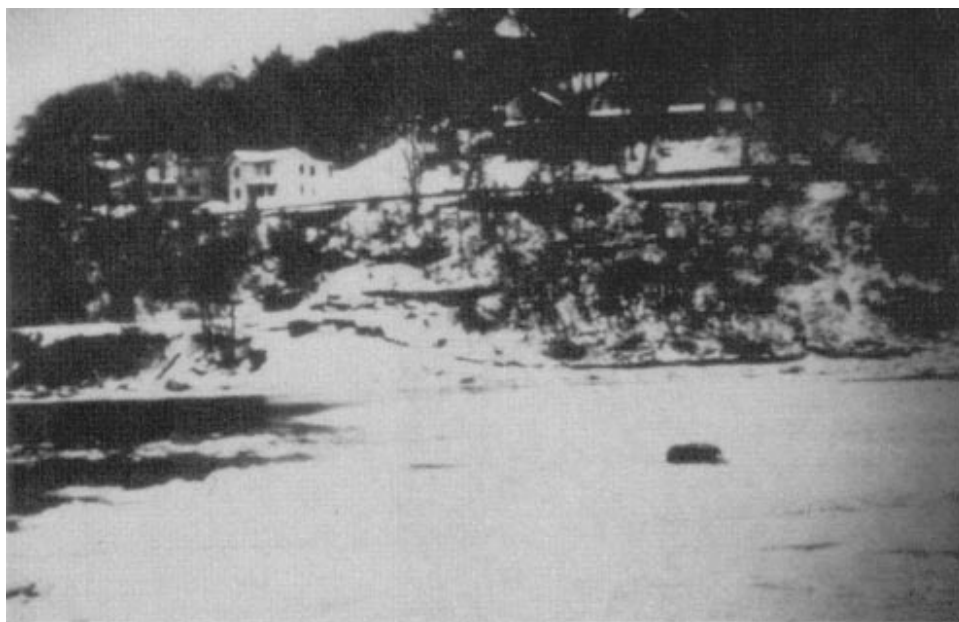


Figure 4-3. Submarine net



a. Prior to freezeup



b. After freezeup

**Figure 4-4. Ice boom on Allegheny River near Oil City, PA**



**Figure 4-5. Ice piers for breakup control**

to limit the rise in upstream water level and corresponding load on the structure elements as well as upstream flooding potential.

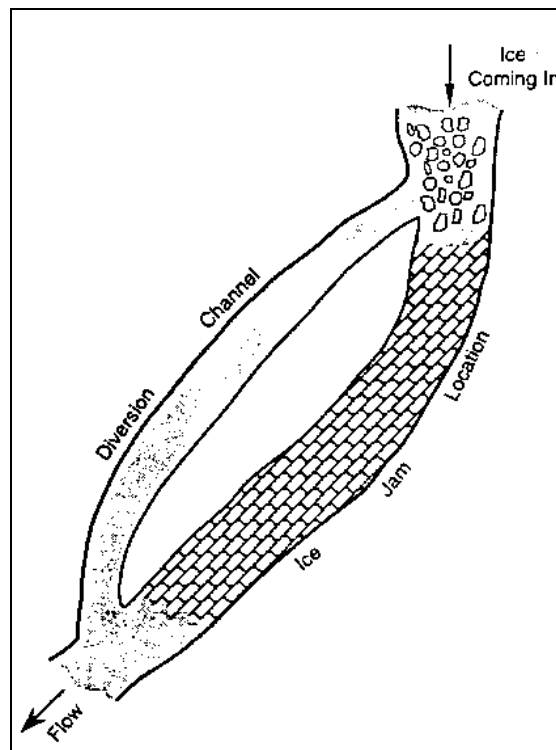
(2) Suspended structures may be placed seasonally, but require adequate permanent anchoring to withstand the ice forces. These structures are generally more suited to smaller rivers and streams. The size and anchoring of projecting structures such as piers, boulders, or cribs must be determined to withstand the anticipated ice forces, and their spacing is a function of the average ice floe size.

(3) This type of jam control does not block the entire river width but allows for recreational navigation and fish passage. Therefore, it can be installed permanently. The bed of the stream may need to be protected against scour around all elements of this type of structure to ensure that they remain stable.

*e. Channel modifications.*

(1) Modifications to the river channel can improve the passage of ice through reaches where ice jams tend to form, such as changes in slope, river bends, slow moving pools, and constrictions. Dredging or excavation can widen, deepen, or straighten the natural channel. Old bridge piers and natural islands and gravel bars can be removed.

(2) Diversions (Figure 4-6) can bypass ice and water flow around the normal jamming sites, lowering the upstream stage. When diversion channels are used, they should be designed to remain dry except during flood events so they will be available to function as open water channels and not contribute to the downstream ice supply.



**Figure 4-6. Schematic of diversion channel for ice jam flooding control**

A diversion channel can improve performance of an ice control structure. If an ice control dam or weir is used to control a breakup ice run, an associated high-level diversion could be used to limit the discharge reaching the structure, reducing river stages to prevent local flooding and ensuring the stability of the ice being retained.

*f. Creation of ice storage zones.*

(1) Breakup ice jam frequency and flood levels can be reduced through storage of ice upstream from damage-prone areas in ice storage zone sites (Figure 4-7). Ice storage zones reduce the volume and/or rate of ice moving to a downstream jam location. By developing low overbank areas where ice can easily leave the channel during breakup, perhaps supplemented by dikes or booms to redirect ice movement, the volume of ice passing downstream can be substantially reduced. The ice left behind settles in side channels, the floodplain, or on the riverbanks.

(2) Ice storage zones can be designed to enhance natural jamming. Measures such as minor channelization, tree removal, bank regrading, berm construction, and installation of booms, piers, or other in-stream structures can be employed to initiate an ice jam at a location where ice storage will be maximized, damage will be minimal, and potential for failure and release of the jammed ice is low.

*g. Thermal control.*

(1) Thermal control of ice jams uses an existing source of warm water to melt or thin a downstream ice cover. Water, even a fraction of a degree above freezing, can be quite effective in melting ice over a period of days or weeks (Wuebben, Gagnon, and Deck 1992). External heat sources include cooling water effluent from thermal power plants, wastewater treatment plant effluent, and groundwater.

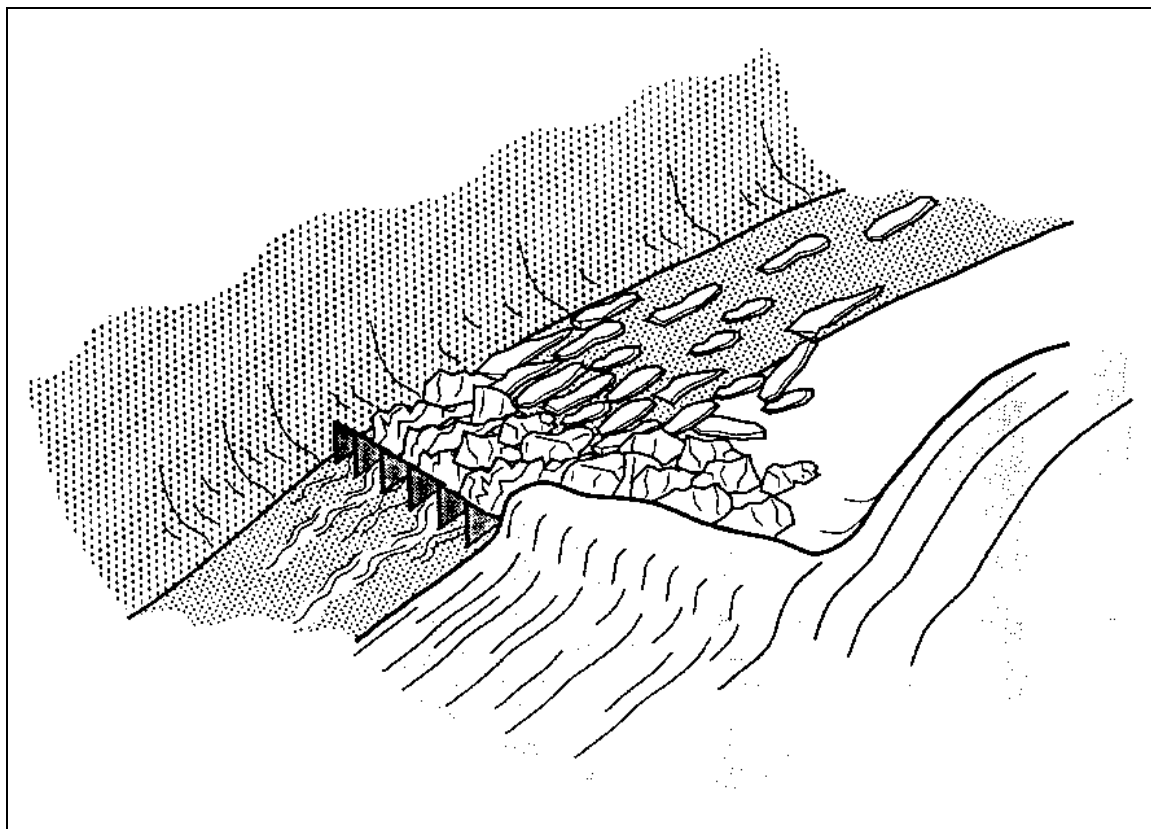


Figure 4-7. Schematic of ice storage zone combined with ice retention structure



The thermal reserve provided by water in nearby lakes and large reservoirs may also be a source of warm water for thermal control. Because water reaches its maximum density at a temperature of about 4 °C (39 °F), colder water in lakes tends to stratify above warmer water. An ice cover can form on the water surface even though the water at depth is still well above freezing. Warm water can be brought to the surface using air bubblers, pumps, or flow enhancers; or a low-level outlet in a dam may be used to release warm water.

(2) Warm water inputs can thin an ice cover prior to breakup so that it will not provide a jam initiation point. Warm water inputs can also reduce the volume of ice available to jam. Thermal control may be used to melt or thin an existing ice jam, thereby increasing the flow area within the jam and decreasing upstream water level.

*h. Floodplain land use management and mapping.*

(1) The best strategy for reducing flood losses is to keep people and property out of the floodplains. Proper land use planning would dramatically reduce the flood damage potential. This is particularly applicable in areas that experience chronic flooding.

(2) Floodplain mapping is essential for careful land use decision making. More than 20,000 communities have floodplain maps prepared by the National Flood Insurance Program. Since most flood insurance studies were prepared for open water flood events, ice jam flooding may not conform exactly to the regulatory or mapped floodplains. However, these maps remain useful tools for determining general floodplain boundaries and elevations.

*i. Floodproofing.*

(1) There are four basic types of floodproofing to minimize damage to individual structures during floods. These are: raising or relocation of a building, barrier construction, dry floodproofing, and wet floodproofing (Figure 4-8). Specific techniques of floodproofing are presented in the USACE manual on floodproofing (USACE 1991).

(2) Raising a building usually involves jacking it up and setting it on a new, higher foundation so that the inhabited areas and utilities are above predicted flood levels. Care must be taken that the new foundation can withstand the expected forces due to water flow and ice and debris loading. Sometimes this requires openings to allow flow through the new foundation. Relocation of the building to higher ground is quite effective but not always possible or acceptable.

(3) While raising and relocating a building are very effective methods of floodproofing, barrier construction can be equally effective in some cases. Barriers such as berms or floodwalls are constructed around the building to prevent floodwaters from reaching it. Openings in the barrier (for example, a driveway) should be avoided. Possible sources of flow through the barrier, such as seepage through the barrier and inflow from water or sewage lines, should be considered in barrier design.

(4) Dry floodproofing involves sealing the outside of the building to prevent floodwaters from entering. Dry floodproofing is usually only considered for cases where flood levels are less than a few feet above the base of the building because at higher levels, the pressure of the water (and ice) can collapse walls.

(5) Wet floodproofing allows the flood waters to enter a structure while at the same time minimizing damage by relocating utilities such as furnaces or hot water heaters above predicted high water levels. Wet floodproofing can be used where construction of barriers and dry floodproofing are not feasible.

### **4-3. Advance Measures**

Mitigation measures put into place in anticipation of actual ice jam flooding are known as advance measures. These measures are used to reduce vulnerability to ice-jam-related flooding. Some emergency measures, such as ice removal, may also be initiated in advance of flooding.

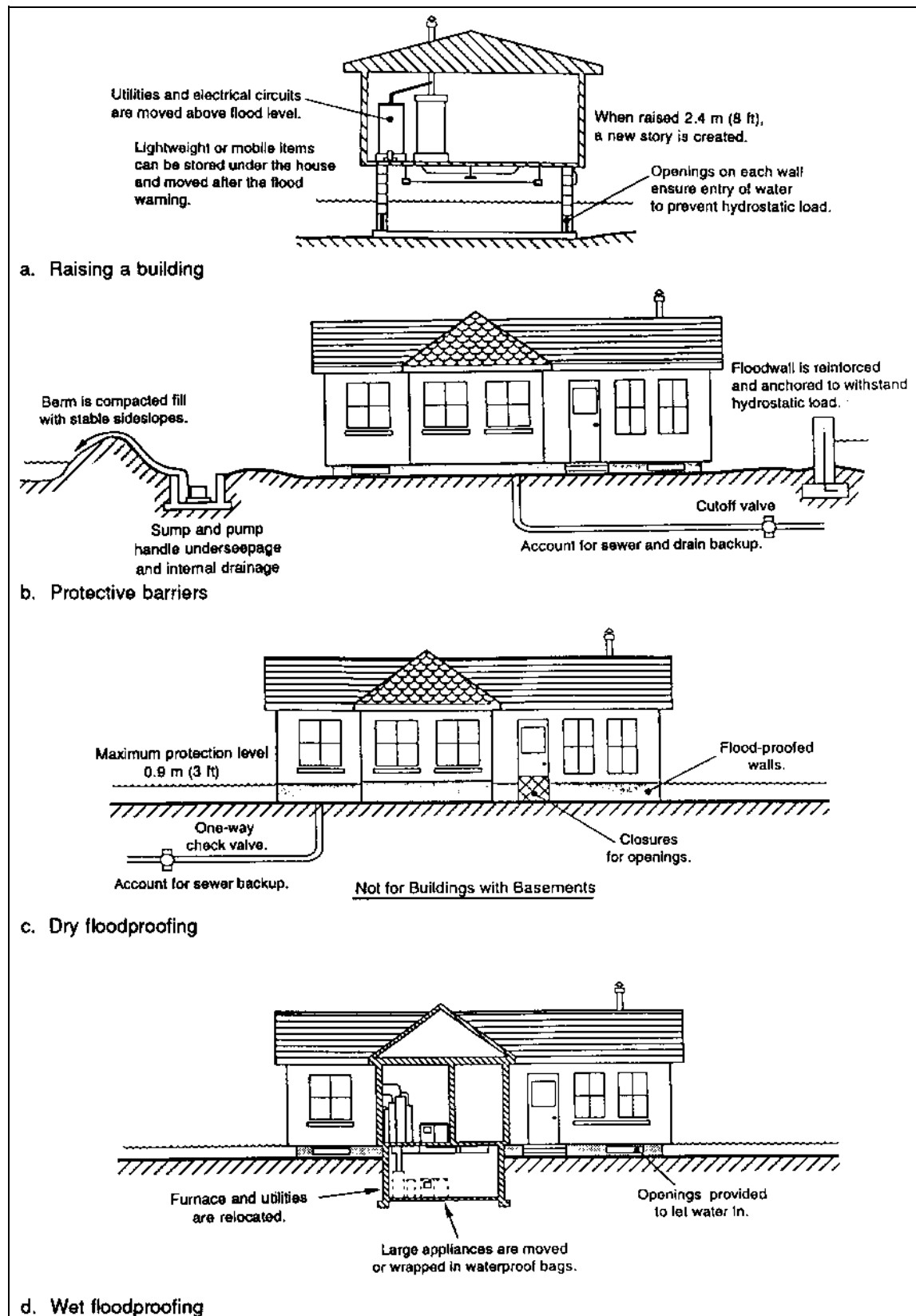


Figure 4-8. Floodproofing techniques (USACE 1991)

*a. Forecasting.* Because of the highly site-specific nature of ice jams, limited available data on ice jams, and the complexity of the hydrologic, meteorologic, and hydraulic processes involved in the formation of ice jams, forecasting ice jam flooding on a general level is not yet feasible. However, it is possible to analyze various ice jam parameters and develop a range of values that can be used to estimate the likelihood of a particular ice jam occurring under certain conditions (Wuebben, Gagnon, and Deck 1992). As more communities adopt flood detection systems, forecasting potential to reduce losses improves.

*b. Monitoring and detection.*

(1) The effects of ice jam flooding are often more localized than those of open water floods. Therefore, it is difficult to generalize ice jam data regionally. Since analytical techniques are less developed than those for open water floods, there is a stronger need for local historical data to serve as the basis for policy making.

(2) Simple remote gauges to collect data on river ice movement and breakup are useful. Water level gauges can detect any rapid increase in river stage, which often precedes ice breakup. Automated temperature sensors help to verify whether conditions are conducive to ice jam formation or breakup. Ice motion detectors (Zufelt 1993) can be imbedded in intact ice covers prior to breakup to give advance warning of the initiation of breakup upstream from a likely jam site (Figure 4-9). Existing gauges can be augmented with telemetry transmitters that send data directly to a local monitoring center or state and Federal agencies (e.g., National Weather Service or U.S. Geological Survey) by telephone, radio, or satellite.

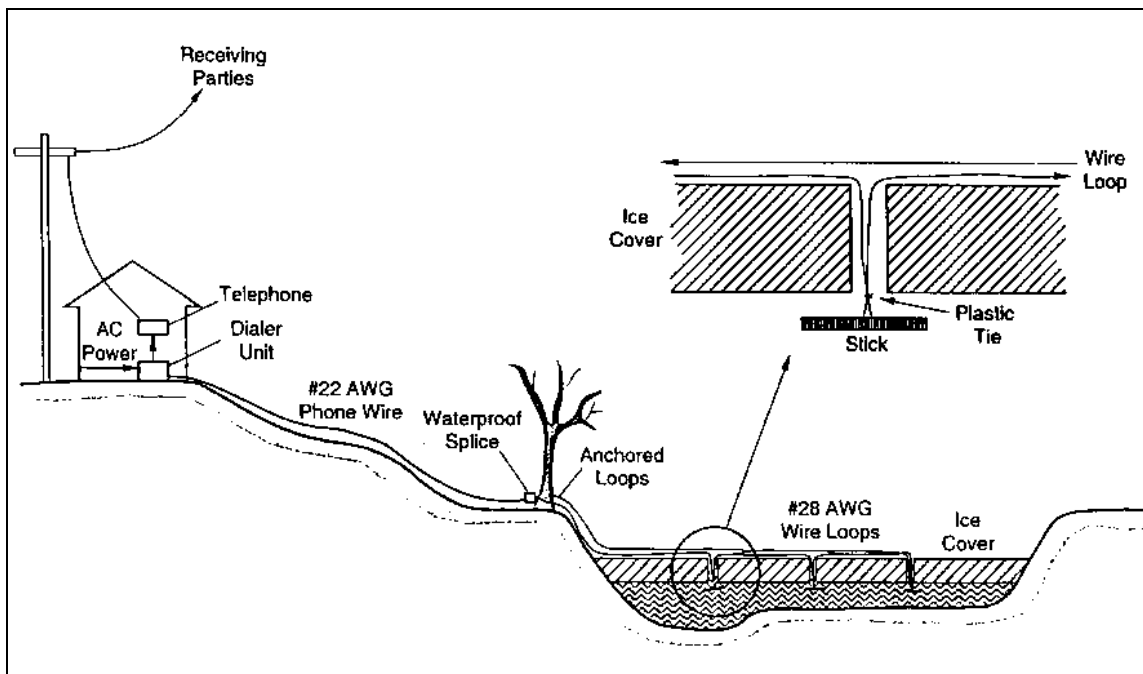


Figure 4-9. Schematic of ice motion detectors

An effective warning system must include a fully developed response system in addition to a detection system in order to save lives and reduce property damages.

*c. Ice cutting.*

(1) Mechanical or thermal ice cutting creates areas of weakness in an ice cover. This technique may be used to cause a stable ice sheet to break up earlier than normal, preventing it from acting as an obstruction to movement of upstream ice. On the other hand, ice cutting in selected locations can create a flow path for ice and water at breakup, reducing the probability of jamming.



(2) Ice cutting (Figure 4-10) involves carving trenches in the ice either mechanically, using a chainsaw, a trenching machine, a backhoe, or some other convenient device, or thermally, using a source of warm water or a substance that reacts chemically with the ice and melts it. The trenches can be partial or the full depth of the ice. They may follow the natural thalweg of the river channel, be cut along the edges of the channel to facilitate movement of the ice sheet, or be cut in a pattern designed to weaken the ice sheet. Ice cutting must be carefully timed to avoid refreezing the slots.

*d. Revised operational procedures.* Flow control may be available at dams or navigation structures located upstream or downstream from an ice jam problem site. The pool level can be raised or lowered to change the location of jamming in the river above the pool. Lowering the pool level early in the winter may expose some frazil ice production areas that would otherwise be covered. Lowering the pool after an ice cover has formed allows additional runoff storage before breakup. Discharge can be lowered at critical periods during ice formation to lower velocities and induce rapid and more extensive ice cover formation downstream. At breakup, lower discharge can decrease ice jam flooding or, in some cases, eliminate ice jam formation.

*e. Dusting.*

**Figure 4-10. Ice cutting**

(1) Covering ice surfaces with a thin layer of dark material induces more rapid melting and ice weakening (Figure 4-11). Conventional materials include coal dust, fly ash, top soil, sand, and riverbed material. Initial tests with biodegradable materials such as leaves, mulch, and bark show promising results. This type of material is more easily spread than sand or coal dust by commercially available seeders and spreaders, but must be dry enough to flow freely for even distribution and to avoid freezing. Wind can be a problem, causing the fine materials to drift or snow to drift over the dust (Moor and Watson 1971).

(2) The dusting material is usually applied 2 to 3 weeks before breakup. The degree of melting depends on the quantity and material properties of the material deposited, solar radiation, and snowstorms. In areas where late snowstorms occur, several applications may be necessary. The melting period may be too short for significant reduction in ice volume or weakening if breakup occurs rapidly.

(3) The possible adverse environmental impacts of dusting materials must be considered prior to application.



**Figure 4-11. Ice dusting**

#### **4-4. Emergency Measures**

##### *a. Phases.*

(1) Emergency measures are those taken after an ice jam has formed and flooding is imminent or already occurring. The effectiveness of emergency response may be reduced unless an emergency action plan exists that specifically refers to ice jams. Comprehensive emergency management includes four phases: preparedness, response, recovery, and mitigation. Emergency planners should have a clear line of command for multigovernmental management of ice jam flooding events. Plans should be tested in advance to be sure that all phases can be carried out and that all necessary materials and equipment are available when needed.

(2) Before implementing emergency measures, it is necessary to monitor the river ice conditions upstream as well as downstream from the jam site in order to select the best measures and to eliminate those that may only displace the flooding problem to another location. Early ice monitoring can also provide lead time to allow other emergency measures to be taken. For example, ice jam progression rate is important in freezeup ice jams, particularly when severe cold conditions conducive to rapid progression are forecast. For breakup jams, knowledge of the upstream ice thickness, extent, and relative strength is needed in estimating the remaining ice supply to the jam. The downstream ice conditions also need to be assessed, if only to determine whether or not there is sufficient open water area to receive ice when the jam releases.

(3) Ice jam emergency response measures include specific measures of ice breaking, mechanical ice removal, and ice blasting in addition to the traditional flood fighting efforts of evacuation, levee closing, and sandbagging, all of which qualify as advance measures.

##### *b. Ice breaking.*

(1) Ice covers can be broken prior to natural breakup using ice breaking vessels or construction equipment (Figure 4-12). Downstream movement of the broken ice should be enhanced to prevent localized breakup ice jams. Ice breaking is particularly useful to ease navigation in larger rivers and lakes.



**Figure 4-12. Icebreaking vessel**

(2) Reinforced lake tugs and river icebreakers are used to clear harbors and rivers, primarily in the Great Lakes system. However, icebreakers are expensive and cannot be used in small rivers of limited depth. Lack of availability on short notice and difficulty of access to the ice in upstream reaches can limit this method.

(3) On large rivers open to commercial navigation, towboats are used to break a channel through level ice or localized ice accumulations. The most powerful towboats available are needed for this purpose. Ideally, two or more towboats work in echelon (staggered, one behind and to the side of the other), with the largest towboat in the lead.

(4) Air cushion vehicles (ACV) can break large extents of relatively smooth sheet ice covers, usually in areas where the sheet ice may stop the ice run and initiate a jam. The advantages of an ACV are its speed and maneuverability and its ability to operate in shallow areas. Disadvantages are that it breaks the ice but does not move it, cannot operate over rough ice accumulations because of potential damages to its flexible skirts, and operation in cold weather can lead to severe icing of the propulsion system.

(5) Construction equipment can be used to break up an ice cover or an existing jam either from the shore or, if the ice is safe, from the river itself. It is generally best to begin at the downstream end of the ice cover and work upstream so the broken ice will be carried away. A heavy weight or wrecking ball can be dropped repeatedly on the ice surface to break up the ice (Figure 4-13). Ice can be broken either to form a channel or weaken the ice in specific locations.

*c. Mechanical removal.* Mechanical removal involves taking the ice out of the river and placing it elsewhere using bulldozers, backhoes, excavators, or draglines, starting from the downstream end of the ice accumulation (Figure 4-14). This approach is most effective on small streams because of the time required to excavate and additional safety concerns associated with wide or deep rivers. Mechanical removal can be expensive and slow but also quite effective. The lack of heavy equipment access to an ice-jam site is frequently an impediment to mechanical removal of ice.



**Figure 4-13. Ice breaking using a heavy wedge suspended from a crane**

*d. Ice blasting.*

(1) A popular solution to ice jam problems, blasting breaks up an ice cover or loosens an ice jam so that it is free to move.

(2) Absolute prerequisites to successful blasting are that there be enough flow passing down the river to transport the ice away from the site and sufficient open water area exists downstream to receive the ice. Otherwise, the ice will simply rejam elsewhere and cause problems for another community. Blasting has been used to remove or weaken strong lake ice that initiated breakup jams at tributary-lake confluences or to create a relief channel within a grounded jam to pass water and decrease upstream water level. As for ice breaking and mechanical removal, it is recommended that blasting proceed upstream from the toe of the jam.

(3) While very dramatic, blasting is not a quick and easy solution. Blasting requires planning to locate and acquire the explosive, the equipment to drill holes, and the personnel. To be effective, the charge should be placed below the surface of the ice, which may be dangerous or impossible during an ice jam event. If the sheet ice or jam is stable, holes can be drilled at regular intervals from the surface to receive the charges. If not, the charges need to be dropped from a helicopter into existing openings in the ice cover.

(4) To blast from the top of the ice, certain procedures should be followed to maximize the degree of success. It is important that each charge be placed in the water immediately below the ice for the large gas bubble resulting from the blast to be most effective in breaking the ice. The charges should be weighted to sink but also roped to the ice surface so that they remain as close as possible to the ice underside and are prevented from being carried downstream by the current. As shown in Figure 4-15 (adapted from Mellor 1982), the diameter of the hole of the crater in the ice is primarily a function of charge weight and is relatively independent of ice thickness. For example, a charge size of about 18 kg (40 lb) will create a hole of 12 to 14 m (40 ft to 45 ft) in diameter for ice thickness ranging from 0.3 to 1.8 m (1 ft to 6 ft). Two more-or-less parallel rows of charges, set close enough so that the craters intersect, usually give the best results by creating a wide enough channel to preclude most secondary jamming. As much as possible, the thalweg of the river should be located and the blasting line placed along it.

(5) Although any kind of explosives can be used, experience has shown that ANFO works well. ANFO is a mixture of 6 percent (by weight) of fuel oil with prilled ammonium nitrate fertilizer, or approximately 0.0037 cu m (1 gal) of oil per 45.4 kg (100 lb) of fertilizer. The mixture must be detonated with a strong booster such as a stick of dynamite, TNT, or other special booster charges sold by powder companies. The ANFO charge must be kept dry, and it is recommended that it be placed in a plastic bag that can also hold the weight (such as a brick or sandbag) necessary to sink the charge. ANFO will dissolve with time if a misfire takes place. This will avoid leaving live charges on the river bottom. As a guide, it is preferable to use Primacord for all downhole and hookup lines. The charge is then set off with one electric cap that is taped to the Primacord at the last moment after the blasting party is off the ice (see Figure 4-16).

(6) Safety and environmental concerns must be addressed before implementation (USACE 1982). In particular, blasting in populated or developed areas may lead to damages to surrounding buildings from falling ice chunks. In general, blasting should be a last resort.



a. Using a dragline



b. With a backhoe

**Figure 4-14. Ice removal**



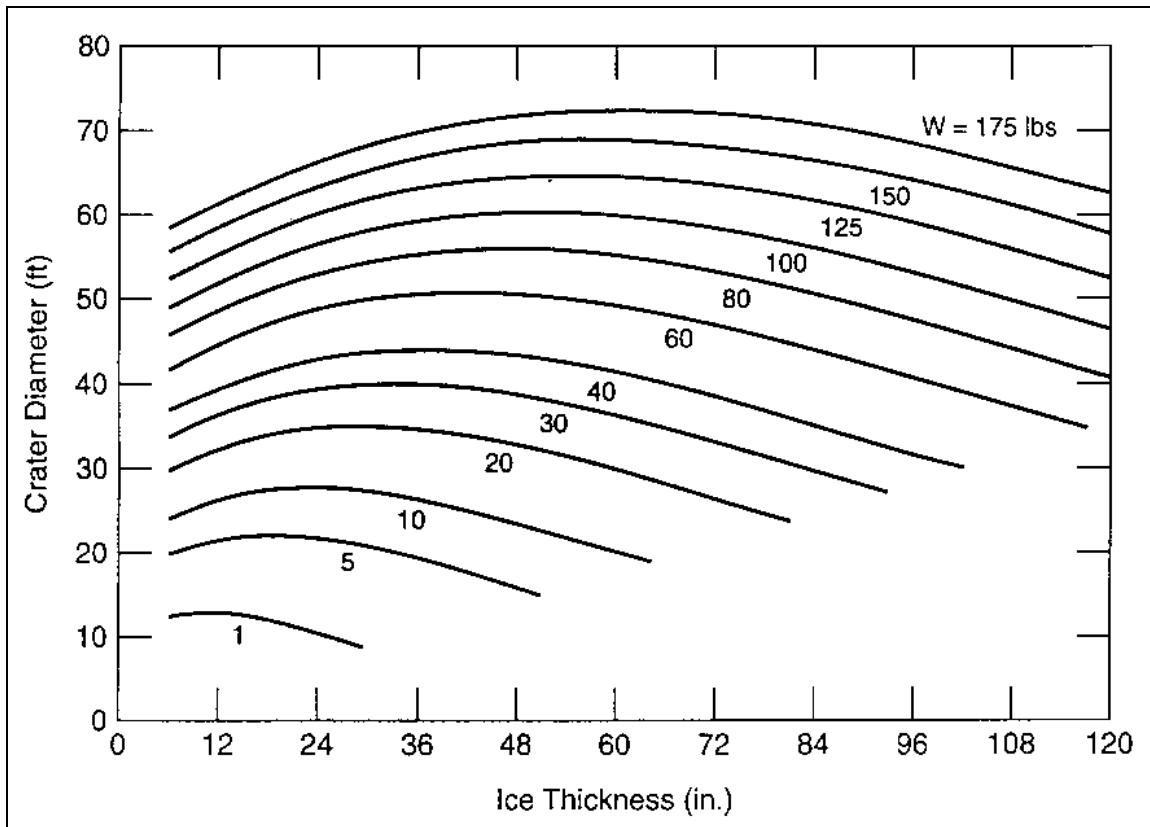


Figure 4-15. Crater hole diameter as a function of ice thickness and charge weight



Figure 4-16. Ice blasting

*e. Evacuation.* The principle behind evacuation is to move people at risk from a place of relative danger to a place of safety via a route that does not pose significant danger. Local law enforcement departments usually serve as lead organizations with standard operating procedures. Winter weather conditions should be taken into consideration when planning evacuation timing, equipment, and routes.

*f. Levee closing.* If ice jam flooding has been predicted, levees should be closed immediately and interior drainage pumps prepared for possible activation. Again, winter weather conditions that can hinder levee closing, such as snow drifts or frozen valves, should be identified. Monitoring water levels at levees may aid in the identification of possible overflow sites before serious damage can occur.

*g. Sandbagging.* Although ice can cause significant damage to sandbags used as protective barriers, the use of sandbagging as an emergency response measure can be very effective in reducing damages at particular facilities or locations. For example, sandbagging around sewage treatment plants or low points on roads or river banks can significantly reduce flood losses (see Figure 4-17).



a. To protect sewage treatment plant



b. To protect downtown buildings

**Figure 4-17. Use of sandbags in Oil City, PA, in anticipation of ice jam flooding**